Development of Immersive Learning in a Virtual Reality Environment (ILVRE) system to assist Construction Education

Mohd Fairuz Shiratuddin
School of Construction, The University of Southern Mississippi,
Hattiesburg MS 39402, mohd.shiratuddin@usm.edu

Tulio Sulbaran
School of Construction, The University of Southern Mississippi,
Hattiesburg MS 39402, tulio.sulbaran@usm.edu

Abstract - **This paper describes the development of an Immersive Learning Virtual Reality Environment (ILVRE) system that can be used as a teaching and learning tool. The system consists of four major components; hardware, interaction technique, software development tool, and teaching/learning content. The fourth component i.e. teaching/learning content has three sub-components; Instructor/Administrator Module, Learner Support Module, and Simulation Module. The first two modules are yet to be developed, while the development of Subject's Module is described in this paper depicting the development of an interactive VR model of a wall section. The ILVRE goals are 1) to create an interactive VR environment where students can explore the educational virtual world, 2) promote an atmosphere where students are directly involved with their learning process, and 3) allow students to have knowledge-building experiences, have the opportunity for trial and errors, and solve problems creatively, without the fear of making costly mistakes or unsafe decisions as they would have in real situation.**

Index Terms – construction education, HMD, immersive learning, Virtual Reality

INTRODUCTION

This paper describes the development of an Immersive Learning Virtual Reality Environment (ILVRE) that can be used as a teaching and learning tool by the School of Construction at The University of Southern Mississippi. A proof-of-concept prototype was developed and will be integrated into the BCT 544 - Building Structures course. Future implementation of the system will be integrated into other courses offered by the School.

An Immersive Virtual Reality environment is a computer generated Virtual Reality (VR) system that includes the 'immersion' property. Various definitions of VR have been offered in literatures. Bryson [1] defines VR as "the use of computers and human-computer interfaces to create the effect of a three-dimensional (3D) world containing interactive objects with a strong sense of three-dimensional presence". Aukstakalnis and Blatner [2] define VR as "a way for humans to visualize, manipulate and interact with computers and extremely complex data". As defined by Rheingold [3], VR is an experience in which a person is "surrounded by a 3D computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it." VR environment holds certain features that distinguished it from 2D and 3D environment. Among the features are visual interface (visualization), immersion, interaction, and presence. Visualization is described as the 'act or process of interpreting in visual terms or of putting in visual form' [4]. Visualization offers substantial difference from 2D and 3D is because of its medium [5]. 2D and 3D viewing is restricted on screen, gives one the sensation of looking through a window into a miniature world on the other side of the screen, with all the separation that sensation implies, whereas VR environments makes it possible for one to become immersed in, and interact with life-sized scenes.

Previous research has shown that an immersive VR environment has the potential to assist and enhance learning experience of the students [6] [7]. Some examples where VR is incorporated for educational purposes are: at the Syracuse University, students were able to simulate flight over various regions of New York State, and engage in virtual tours of national landmarks, such as Niagara Falls [8]; from the early 1990s to date, through the creation of The Learning Sites, efforts are continued by its members in creating archeological virtual worlds for educational purposes [9].

ANTICIPATED IMPACT

According to Siddens, the obvious educational benefits of VR technology is based on its ability to present information in a way that cannot be captured by traditional and conventional 2D approaches. Research at the Human Interface Technology Laboratory (HITL) at the University of Washington [10] [11] provides an intuitive sense that VR could be highly useful to promote skills and knowledge which students can apply across many domains. The interactive and immersive qualities of VR suggest the potential for an entirely new form of experiential learning. The use of VR appeared to help integrate course concepts together [12].

Developments in education have ventured in integrating VR technology in constructivism, which considers how students learn and interpret the information presented. Immersive VR environment has the potential to provide an environment for constructive learning and emphasize students' ability to solve real-life, practical problems [13]-[15]. Students work in teams rather than individually, tend to focus on projects that require solutions to problems rather than on instructional sequences that require learning of certain content skills. The job of the teacher is to arrange for required resources and act as a guide to students while they set their own goals and 'teach themselves' [16].

Students will experience more stimulating learning environment due to the subject being presented to them in a realistic VR environment. It is reported that students are more receptive to new information when the information presented to them are interesting and exciting, where this is termed as 'information-rich' learning environment [17]. It is also found that when VR is used in construction education, VR provides students with enhanced understanding of a subject [18]. This is because students have the opportunity for trial and errors, and solve problems creatively, without fear of making costly mistakes or unsafe decisions as they would have in real situation.

Using the ILVRE system, students will have high degree of control over their self-paced learning and navigations through a VR environment, hence may result in each student having a unique learning experience. Students also have the opportunity for repeated access to learning materials, while teachers can continue improving the teaching materials, and use the materials year after year.

SYSTEM DEVELOPMENT

We divide the ILVRE system into 4 major components; the hardware, the interaction technique, the software development tool and teaching/learning content.

The Hardware

Implementing an IVE for teaching and learning purposes may induce unacceptable cost to many academic institutions with limited budget. Initially we planned to have a fully-immersive VR environment using a CAVE™-like display. We discovered, although cost may not be as expensive as we initially thought, the prohibitive factors are space requirement and maintenance. To have permanently CAVE™-like display setup requires at least 10-square foot amount of space to comfortably accommodate 2 to 3 users, computers, projectors, cablings and projection-screens. A CAVE™-like display also requires some form of regular maintenance if it is to be used on regular basis, hence may require a technician to be in charge of maintenance. Because of such limitations, a combination of a head-mounted-display (HMD) and data-glove was used instead.

A HMD is used to display the VR environment, and a right-handed data glove for user interaction purposes. Although the HMD is not as fully immersive as a CAVE™ display, it can to a certain degree instigate "a suspension-of-disbelief", allowing students to feel immersed in the VR environment. We used the z800 model HMD from eMagin (Figure 1) costing approximately $900. The z800 model uses two high-contrast and bright SVGA 3D OLED microdisplays instead of LCD. It has a built-in 360-degree angle of view head-tracker for 3-degrees of freedom movements and also can emulate the 2D mouse pointer movement. The HMD's head-tracker mouse emulation allows many VR applications that support mouse-viewing to utilize the tracker without any specialized hardware driver to be coded and installed. This provides a major advantage, since many high-end VR head-trackers require specific lines of codes to be embedded in the VR application itself. The z800 HMD is also comfortable to wear since it weighs only 8 oz and does not cause strain on the user's neck.

FIGURE 1
THE Z800 HMD AND P5 GLOVE

The p5 data-glove (Figure 1) was developed by Essential Reality and intended for computer and video gaming purposes. We use it because it is low-cost compared to other data glove in the market. The p5 glove uses bend sensors and it has its own 6-degree of freedom infra-red wireless tracking mechanism. Each bend of the finger can be programmed to emulate a command on the PC e.g. bending the index finger twice will emulate the double-left mouse button click, bending the index finger once will emulate the left mouse button click and hold, and drag command. Our initial experience with our students is that they require some form of familiarization in using the glove, and once comfortable, interaction with the ILVRE system is almost second nature. Even though the p5 glove is lightweight, prolong use can cause strain on the arm, hence students were asked to sit on a chair with arm-rests rather than to stand. Figure 2 shows one of our students using the HMD and the p5 glove.

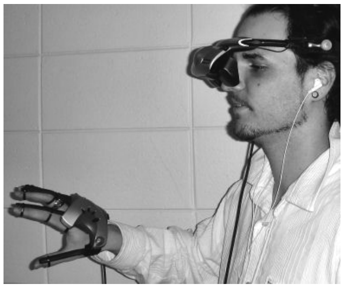

FIGURE 2
A STUDENT USING THE ILVRE SYSTEM

The Interaction Technique

In any VR environment, suitable interaction techniques play an important role for user to effectively and efficiently interact with the objects in the VR environment. To date, our ILVRE system only use the classic double and single mouse clicks on a 2D plane. This interaction technique immediately allows our students to be familiar with navigating and interacting with the objects in the VR environment.

In our next phase of research, we plan to apply and investigate the effectiveness of 3D interaction techniques for our ILVRE system. We anticipated that, redesigning of the current 2D plane user-interface is imminent to support 3D interaction techniques in a VR environment.

The Software Development Tool

We developed the prototype learning system using extensible 3D or X3D. X3D is extensible and can be expanded. Modifications and improvements will be needed from time to time as more content is added. X3D is the successor of VRML (Virtual Reality Modeling Language) and considered to be more matured. It is an open standard XML enabled 3D file format that enables real-time (or near real-time) communication of 3D data across applications and networks [19] allowing users to experience 3D graphics and multimedia on the Internet.

We used VizX3D to speed up the software application development process. Once developed, the VR environment can be displayed in any internet browser such as Microsoft Internet Explorer or Netscape Communicator. VizX3D is a product developed by Virtock Technologies. It is a 3D visual authoring tool that has a CAD-like interface. It uses the familiar Windows GUI framework and allows the user to either import their own VRML code, export interactive 3D scenes as VRML and X3D, provides a unique trigger system that allows users to create interaction logic by selecting nodes, and selecting phrases to complete sentences to describe the desired behavior. VizX3D also provides the user with the basic 3D shapes or primitives needed to create a VR environment (Figure 3). Users only need to drag and drop primitives into one of the viewports, and then deform the shapes by changing its dimensions and shape accordingly.

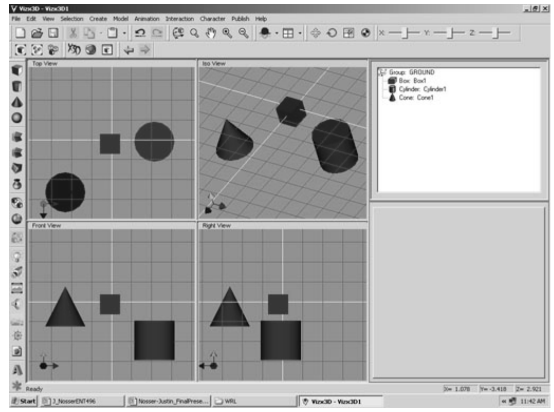

FIGURE 3
A SCREENSHOT OF VIZX3D

There are no recommended hardware requirements for VizX3D, but to achieve an acceptable rendering quality at least a minimum rate of 30 frames per second (fps), we suggest that a desktop home computer equipped with a good 3D graphic accelerator card.

Teaching/Learning Content

For initial testing purposes, two learning environments were developed: 1) the layers of a wall showing sub-assemblies, and 2) the inner workings of a typical HVAC system. In this paper we describe the development process of the wall assembly learning environment. Two modes were developed; interactive and non-interactive. In the non-interactive mode, students were presented with animations e.g. an animation showing a wall is assembled. In the interactive mode, using the p5 glove students were asked to assemble the wall themselves by dragging the right sub-assembly in the right sequence.

The main components of the teaching/learning content are: (1) The Instructor/Administrator Module, (2) The Learner Support Module and (3) Simulation Module. Modules (1) and (2) are yet to be developed. However, in this paper, we described the development of the Simulation Module that encompasses of an interactive VR environment of the wall assembly.

I. Instructor/Administrator Module

This module is planned to be a set of administrative tools to assist the instructor who is in charge of delivering the subject to be taught to students. The module will allow the instructor to track students' progress, post quizzes and questionnaires; generate report, maintaining students' grades etc. Instructors will also be provided with guidelines for instructional techniques, delivering learning outcomes, and evaluating learning outcomes. The functionally of this module could be similar to a Course Management System such as WebCT, Blackboard, or Bazaar.

II. Learner Support Module

This module will consist of a set of tools that will be integrated into the ILVRE system. The tools include learner's evaluation and self-evaluation tools, multi-media (audio, video and 3D models) archives, the course schedule, a glossary database, learner's collaboration e.g. email, dropbox, blogs, chatrooms etc. and presentation areas.

III. Simulation Module (The Development of the Interactive Wall Section)

A 3D model of a wall section assembly was chosen for the proof-of-concept prototype development. Prior to development, the sub-assemblies of the wall section to be modeled in VizX3D were identified. The wall section consisted of a 4" brick wall, a 2" polyurethane wall with a foil side, a 5" wall of concrete, a ½" gypsum board, and for this particular wall section, air space was also considered. A working folder was created to accommodate all the required files e.g. texture images and the X3D files.

In VizX3D, 3D cubes were modeled to represent each layers of the wall section. The dimensions of each layers of the wall section does not comply with architectural units, hence approximations have to be made with regards to the sizes of each sub-assemblies elements. In VizX3D each sub-assembly represent a node. Once all the wall nodes were created, the necessary textures were applied to sub-assembly layers. All the textures required were either downloaded from the internet or created in Adobe Photoshop.

The textures created in Photoshop were saved to a JPEG file format (due to its high compression ratio that will produce small file size) and applied to the respective nodes inside VizX3D. For the air spaces nodes, the animated GIF file format was used to animate arrows and text giving the illusion of air movement. The finished sub-assemblies for the wall section were then moved and placed randomly inside VizX3D. All of the walls and air space nodes were all translated to a y-coordinate value of 0 so that they appear to be standing on a flat plane inside of VizX3D (Figure 4).

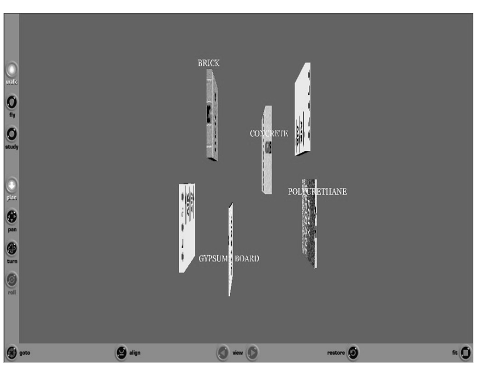

FIGURE 4
TOP VIEW OF THE WALL SECTION

Then a background node was added The Background node provides the X3D world with an infinite horizon that can be defined using gradient colors or photorealistic textures projected onto the six sides of an infinitely large cube also known as a skybox. Since a photo realistic environment was not necessary, a solid green color was applied for the ground value and a solid blue color for the sky value of the background node. A red sphere node was also created in VizX3D that would later become the start button to start the wall assembly animation.

The next step was to animate the nodes along a path to simulate the elements coming together to assemble a wall section. Once these steps were completed, a touch sensor was added to the sphere. The animation of the red sphere was added as a trigger to the touch sensor so that when the red sphere is clicked by the user, the sphere animation begins and starts the chain reaction of triggering the other nodes. The final result is when the user clicks the sphere, the sphere will disappears, and the wall assembly animation begins one sub-assembly node at a time. This concludes the non-interactive portion of the wall section learning environment

The interactive portion of the learning environment utilized the same 3D model of the wall section. Interactive nodes were added to it that allows students to assemble the sub-assemblies to form the wall section. 3D billboard texts were placed above each wall node so that the user can identify one wall from another instead of solely relying on texture images. The concept of billboard allows nodes to face the user's viewpoint no matter which direction the user navigates. It is similar to the moving eyes of someone in a photograph. No matter which direction one in looking at the picture, the eyes of the person in the photograph seem to follow viewer. The billboard node was placed in every group node that contained 3D text. The billboard node was then moved so that the 3D text would be above the wall nodes. By doing so, the user will be able to read the 3D text from any angle in the VR environment because of the behavior of the billboard.

Lightings were then added to the VR environment so that the wall nodes, air space nodes, and 3D text can be seen clearly. Two directional lights were placed inside the VR environment; one facing the negative x-coordinate direction and one facing the positive x-coordinate direction. Directional lighting depicts a light source from far away such as the sun. The light emitted is parallel to the direction and objects in the scene are affected by it. Viewpoints and navigation information were then added in VizX3D. Three viewpoints choices will be given to the student to view the wall assembly animation from different perspectives; a top viewpoint, a left isometric viewpoint, and a right isometric viewpoint.

Finally, once all the above steps were accomplished, the VR environment was saved and published as X3D file format.

CONCLUSIONS AND FUTURE DEVELOPMENT

Our initial observations upon a few students who tested the prototype system have been positive and encouraging. Our next phase of the research will include a comprehensive Instructor's Module and Learner's Module, finding other suitable subjects/topics to be developed in the ILVRE system, fully integrate the system into the BCT 544 - Building Structures course, investigate 3D interaction techniques, and gather quantitative data on the effectiveness of the ILVRE system to assist teaching and learning.

The ILVRE system goals are 1) to create an interactive VR environment where students can explore the educational virtual world, 2) promote an atmosphere where students are directly involved with their learning process, and 3) allow students to have knowledge-building experiences, have the opportunity for trial and errors, and solve problems creatively, without fear of making costly mistakes or unsafe decisions as they would have in real situation. Some of the benefits that can be gained are:

- Students have the opportunity to visualize and have meaningful interaction with the computer generated model (e.g. students can navigate in a 3D virtual construction site and assemble a wall. This can reduce or eliminates physical visits to construction site which normally requires prior arrangement, permission, and safety issues to be concerned with.
- Teachers can present their material in 3D, where conventionally, teachers describe to students on the board and/or using 2D static images.
- Students have the opportunity for repeated access to learning materials, while teachers can continue improving the teaching materials, and use the materials year after year.
- Students will have high degree of control over their self-paced learning and navigations through a VR environment, hence may result in each student having a unique learning experience.

We believed the ILVRE system is a promising tool to assist teaching and learning. With the cost of VR software and hardware dramatically reduce over the years, plus the advancement of 3D computer graphics, developing such a system is viable.

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